<u>SUBSTITUTE SPECIFICATION (Marked-Up)</u>

PROCESS FOR IMPROVEMENT OF FINGERPRINT IMAGES

<u>Related Application</u>

[0001] <u>This is a §371 of International Application No. PCT/FR2005/050010, with an international filing date of January 7, 2005 (WO 2005/071602 A2, published August 4, 2005), which is based on French Patent Application No. FR 04/50055, filed January 9, 2004.</u>

<u>Technical Field</u>

[0002] The ~~present~~ invention refers to the field of image processing. ~~The present invention refers~~ more specifically to a process for improving the fingerprint images with the aim of facilitating extraction of the parameters necessary for print recognition.

<u>Background</u>

[0003] ~~The former art is already acquainted, though application~~ WO_03/079274, ~~with~~ <u>discloses</u> a process for improving fingerprint images, in which the recorded images are processed based on blocks of the initial image using Gabor filters adapted to characteristic quantities of each block. More specifically, the processing described comprises the following successive stages:

- calculation of the local gradients G of the initial image;

- calculation of the spacing R between the lines, corresponding to the frequency;

- division of the initial image into different blocks;

and subsequently, for each block:

- calculation of the orientation of the block and the variance of the orientation using the gradient G;

- calculation of the frequency of the block and its variance using R;

- construction of Gabor filters based on these parameters;

- filtering of the blocks using the Gabors;

- addition of the filtered block to the final image.

[0004]   The disadvantage of such a method is that the orientations are calculated based on the local gradients of the initial image before application of the Gabor filter(s). This image may be of very poor quality; the errors obtained in the gradient calculations have very harmful consequences on the selected parameters of the Gabor filter(s) and therefore on the quality of the final image used for the extraction.

[0005]   ~~The former art is also acquainted, through the publication of~~ Hong et al. "Fingerprint Enhancement" ~~with~~discloses a print image improvement method. This publication mentions the value of filtering the image by Gabor filters before making choices of orientations. However, the publication uses an average frequency set here at 60 cycles per image height for such Gabor filters.

[0006]   The disadvantage of such a method is that, in reality, it is incorrect to consider that the line spacing is fixed and once again, such a hypothesis is very harmful to the quality of the results.

[0007]   ~~One is also acquainted, through the scientific publication~~ XP_010614029 of Okombi-Diba et al. "Segmentation of spatially variant image textures"~~, with~~discloses a process for ~~char-acterising~~characterizing the image textures and segmenting this image according to these tex-

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tures. The process is based on the use of Gabor wavelets by Gabor filters. Such a process is only used for texture determination.

Summary

[0008]   This invention relates to a process for improving a fingerprint image including normalizing an initial image, determining a useful zone of the image, cutting the image into a plurality of blocks, calculating an FFT of each block, determining frequencies of image blocks based on the FFT, applying Gabor filters of parameters determined by the frequencies, and determining orientations of the image based on filtered images derived from the Gabor filters.

Brief Description of the Drawings

[0009]   Selected, representative aspects of the invention will be better understood with the aid of the description, given here as a mere explanation, of a method of realization of the invention, with reference to the appended figures in which:

Fig. 1 illustrates the pre-processing of the raw image; and

Fig. 2 illustrates improvement of the image by filtering.

Detailed Description

[0010]   ~~The present invention intends to~~We compensate for the disadvantages of the former art by calculating the orientations of the image after filtering adapted to the image. In order to do this, ~~the present invention is of the type described above and is remarkable, in its broadest sense,~~ ~~in that it proposes~~we provide a process for improving a fingerprint image comprising at least the stages of:

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- ~~normalisation~~normalization of the initial image;

- determination of the useful zone of the image;

and characterised by the fact that it comprises in addition successive stages of:

- division of the image into a plurality of blocks;

- calculation of the FFT of each block;

- determination of the frequencies of the image blocks based on the aforementioned FFTs;

- application of Gabor filters of parameters determined by the aforementioned frequencies;

- determination of the orientations of the image.

[0011] ~~Favourably~~Favorably, the aforementioned blocks comprise overlapping zones.

[0012] Preferably, the aforementioned frequencies of the blocks are determined by the highest frequency in a higher energy frequency band.

[0013] Preferably, the aforementioned stage of determining frequencies of the image blocks additionally comprises a stage of evaluating the relevance of the calculation of the values of the aforementioned frequencies.

[0014] ~~Favourably~~Favorably, in case of irrelevance of one of the aforementioned frequencies, the aforementioned frequency is recalculated based on a function of the initial FFT.

[0015] According to ~~a method of realisation~~one aspect, the irrelevance of one of the aforementioned frequencies is assessed in relation to a predetermined threshold.

[0016] Preferably, the aforementioned stage of determining orientations of the image additionally comprises a stage of evaluating the relevance of the calculation of the aforementioned orientations.

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[0017] ~~Favourably~~Favorably, the aforementioned Gabor filters have as orientation parameters 0°, 22.5°, 45°, 67.5°, 90°, 112.5°, 135° and 157.5°.

[0018] Preferably, the aforementioned stage of determining orientations comprises ~~the stages consisting in~~:

    -     reconstituting images based on the aforementioned Gabor filtering of the aforementioned blocks;

    -     calculating the average intensity of each filtered image for zones of a predetermined size;

    -     creating a new image of orientations containing the orientation of the block of the highest intensity;

    -     creating a new quality image containing the intensity of the block of the highest intensity;

    -     filtering of the aforementioned image of the orientations.

[0019] According to ~~a method of realisation~~another aspect, the process additionally comprises stages of creation of a merged final image based on the aforementioned orientations and ~~binarisation~~binarization and ~~skeletonisation~~skeletonization of the aforementioned merged final image for detection of the fine details.

[0020] ~~The invention will be better understood with the aid of the description, given here as a mere explanation, of a method of realisation of the invention, with reference to the appended figures in which:~~

    ~~figure 1 illustrates the pre-processing of the raw image;~~

    ~~figure 2 illustrates improvement of the image by filtering.~~

[0021]   Illustrated in ~~figure~~Fig. 1, the first functional block ~~according to the invention~~ is a pre-processing block. It allows the image to be subsequently processed under satisfactory conditions.

[0022]   This block takes on input the raw image Ib derived from the fingerprint sensor and applies various different pre-treatments to the raw image. These pre-treatments are of a known type and ~~consist of normalisation~~include normalization of the image, in addition to an initial determination of the useful zone of the image, i.e. the zone containing the print image.

[0023]   For global ~~normalisation~~normalization, the overall mean of all the pixels of the image is established, in addition to the standard deviation at a predetermined value, for example mean = 127 and standard deviation = 50 in shade of grey.

[0024]   Thus, if N=L*H is the total number of pixels of the raw image and Ib (x) is the value of the xth pixel of the raw image, one calculates:

$$M_b = \frac{1}{N}\sum_{x=0}^{N-1} Ib(x)$$

and subsequently the deviation $D_b = \sqrt{\frac{1}{N}\sum Ib(x)^2 - M_b^2}$

and the new ~~normalised~~normalized image is, if the new mean has been set at M_0 and the deviation at D_0:

$$In(x) = M_0 + \frac{(I_b(x) - M_b) \times D_0}{D_b}$$

[0025]   A mask of known type is also applied based on the local means and standard deviations. Based on this useful zone, the image is cut again. Cutting the image again serves two purposes: on the one hand, it allows a reduction in the size of the image in order to reduce the processing time during generation of the template. This reduction in the size of the image also makes it possible to limit the risks of false detection of fine detail at positions in the image that

are not part of the fingerprint itself. Furthermore, it allows generation of an image, the size of which will be a multiple of the size of a certain number of overlapping blocks, used for image improvement, in order to facilitate processing of these blocks.

[0026]   At the end of this initial stage, a re-cut normalised image Ip is obtained.

[0027]   Based on this re-cut image Ip, the functional block of improvement of the image itself illustrated in figureFig. 2 is applied.

[0028]   The image is initially cut into blocks of size Tenh*Tenh, where typically Tenh = 64 pixels. These blocks overlap by Toverlap in order to avoid the effects of edge in the subsequent processing.

[0029]   An FFT algorithm is subsequently applied to each of the blocks in order to obtain their Fourier transformation. One may note that on such blocks, the orientation of the lines in addition to the spacing varies little and therefore the value obtained in the reciprocal space is normally highly localised. However, a mean frequency for the block should be defined.

[0030]   This frequency is obtained in the following manner: one starts by applying the algorithm allowing calculation of the spectrum of the FFT block in polar coordinates. Use of polar coordinates is convenient, since it allows one to readily distinguish the components of the block representing the frequency of these representing the orientation. One subsequently applies an algorithm for detection of the highest frequency in each block. In order to assess this frequency, each block is cut into Nbands frequency bands, where typically Nbands = 8. The highest frequency in the frequency band with the highest energy is subsequently selected. This algorithm also allows assessment of the relevance of its measurement. This relevance value is calculated using a ratio between the energy of the highest frequency of the bands and the mean energy of

the other bands. For certain blocks, the frequency measurement of which is considered irrelevant, a new evaluation is performed by interpolating the value based on the neighbouring values.

[0031] This algorithm therefore makes it possible to obtain a good estimation of the mean frequency of the lines of prints for each block, in addition to a confidence index corresponding to the accuracy of this estimation.

[0032] Conditionally, new processing is employed for blocks the quality of estimation of the frequency of which is too poor. The FFT is globally multiplied by itself in order to increase the frequency peaks and eliminate parasitic low frequencies. A ~~normalisation~~normalization is subsequently performed so as not to generate any saturated data. More specifically, if ReFFT is the real part of the FFT and ImFFT is its imaginary part, one calculates for each point, pseudo-Magnitude(x) = $(\text{Re}FFT(x)^2 + \text{Im}FFT(x)^2)^n$ with n=0.25 typically and one selects as new coordinates of the FFT: ReFFT(x) = ReFFT(x)*pseudoMagnitude(x) and ImFFT(x) = ImFFT(x)* pseudoMagnitude (x). ~~Normalisation~~Normalization is performed in this case by dividing each complex value of the FFT by the Max of the magnitudes of the block.

[0033] The functional improvement block is subsequently applied thanks to this frequency map Freq by Gabor filters.

[0034] Gabor filters are filters which are selective in orientation and frequency. They make it possible to emphasis lines spaced according to a certain frequency and oriented in a specific direction. The principle of our filtering algorithm therefore involves using a bank of Gabor filters, the frequency of which is determined by the frequencies Freq defined above. Different Nori orientations are used in order to define the orientations of the filter bank, with typically Nori = 8 for orientations of 0°, 22.5°, 45°, 67.5°, 90°, 112.5°, 135° and 157.5°. The blocks are filtered by

the Nori filters and Nori images are reconstituted based on the different filtering of the various blocks.

[0035]   Based on these Nori images, one proceeds to determine orientations of the filtered images according to the following process: an initial estimation of the orientation is performed by calculating the mean intensity of each filtered image for blocks of size TblocA, where typically TblocA = 4. One subsequently writes the orientation of the block with the highest intensity in an Ori image and the intensity of this block in qual2.

[0036]   Since the map of the Ori orientations thus obtained presents many discontinuities, a median filter is applied in order to reduce the latter and obtain a more uniform representation.

[0037]   One subsequently searches for all the regions formed by related pixels with the same orientation in the Ori image filtered in this manner. One subsequently proceeds to filter these regions as a function of their size and their orientation in the image. For this purpose, the regions which are too different from their neighbours are replaced according to a predefined threshold, by the most probable orientation, calculated as a function of the orientation and the quality of the different neighbouring pixels of the pixel of the region processed. The quality map qual2 is updated as a function of the intensity of the pixels modified during this processing.

[0038]   The same processing is subsequently employed, but pixel by pixel, in order to reduce the problems due to these sudden changes in orientation. In order to conduct this processing, all the pixels, the value of which is too different from that of their neighbours are sought. One subsequently applies, after dilatation of the image of the pixels to be processed, the same algorithm for replacement of the orientation as above for the pixels to be processed. The quality map qual2 is updated as a function of the intensity of the pixels modified during this processing.

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[0039]	One subsequently searches one last time for the regions which are too different from their neighbours in order to determine whether the processing performed beforehand has or has not had a beneficial effect. If this is not the case, these regions are marked as bad in the quality map qual2.

[0040]	Finally, a median filter is applied to this quality map.

[0041]	As a function of the map of the orientations calculated above, the pixels to be written in the final merged image are selected. Thus, as a function of the map of the orientation, each pixel is selected in one of the Nori images filtered. In order to make these transitions smoother, an interpolation between the different orientations is performed at the boundaries of each block.

[0042]	The merged image obtained in this manner is subsequently ~~binarised~~binarized and ~~skeletonised~~skeletonized continuously in order to allow detection of the fine details, with the quality map qual2 serving to determine the relevance of each fine detail.

[0043]	~~The~~Various aspects of the invention ~~is~~are described in the preceding paragraphs as ~~an~~representative example~~s~~. It is understood that ~~a specialist~~one skilled in the art is capable of ~~realising~~realizing different ~~variants~~aspects of the invention without ~~forasmuch~~ departing from the ~~framework~~scope of ~~the patent~~this disclosure as defined in the appended claims.